4p.

Fig. 2. A view of the hydrostatic pressing facility taken after die failure. Broken die section appears in lower r.h. corner.

~~NASA, Washington, D.C.~~

DETECTIVE STORY: Why did a hydrostatic pressing vessel fail?

6021505 N64 13198 * Repr. from Safety Maintenance, Nov. 1963 CODE NONE (NASA RP-92) 4p

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Hydrostatic pressing is used extensively in processing powdered metal samples at the Lewis Research Center of the National Aeronautics and Space Administration. This versatile processing technique plays an important role in the research investigation of various space-age materials. In this pressing method, samples are compacted by enclosing them in sealed plastic or rubber containers and suspending them within a liquid that is subsequently pressurized. The resulting compacts are sintered to produce further densification prior to mechanical processing or testing.

How press works

A 6,000,000-pound-force hydraulic press is used to develop the necessary hydrostatic pressure. An intensifier composed of a die body and piston (Fig. 1) is placed on the movable platten of the press. Before the piston is inserted into the bore, the die body is prefilled with a suitable grade of oil plus the sheathed samples. As the press platten rises, the piston is driven into the die body cavity compressing the liquid and producing the desired internal pressure. This pressure is transmitted in undiminished magnitude throughout the fluid in all directions and compresses the samples. An adaption of Bridgeman's moving piston seal (Ref. 1) is used to prevent leakage of high-pressure fluid from within the die body.

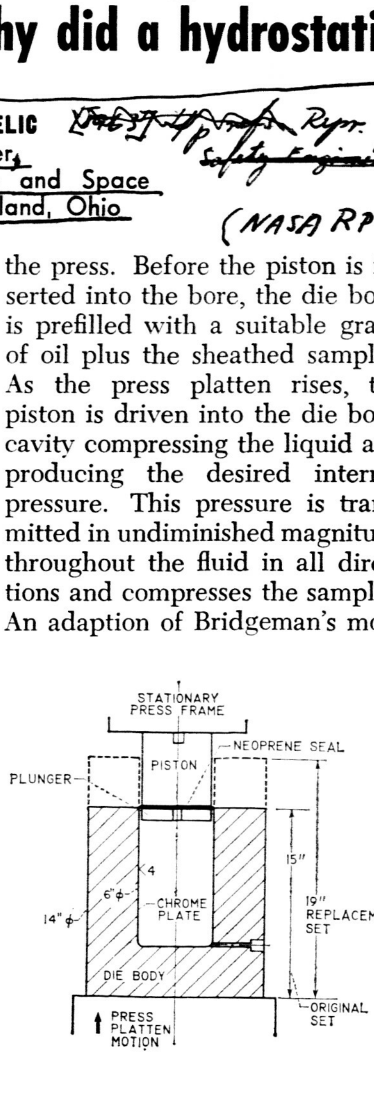


Fig. 1. Picture displays the intensifier die sets which are used for hydrostatic pressing of NAA Lewis Research center.

During the early 1950's the first set of intensifier dies was placed into service at the Lewis Research Center. The die body featured a 6-inch inside diameter and an 11-inch inside length. The original die parts were made from an oil-hardening tool steel (Carpenter "R.D.S.") that was heat-treated to produce a constant hardness of Rockwell-C58/60 throughout the material. A thin chrome plating was applied to the bore of the die body and to the outside diameter of the piston to retard wear and galling. This die set remained in service until October 1961, when it was replaced by a new and longer set. Although no accurate records were maintained during the serv-

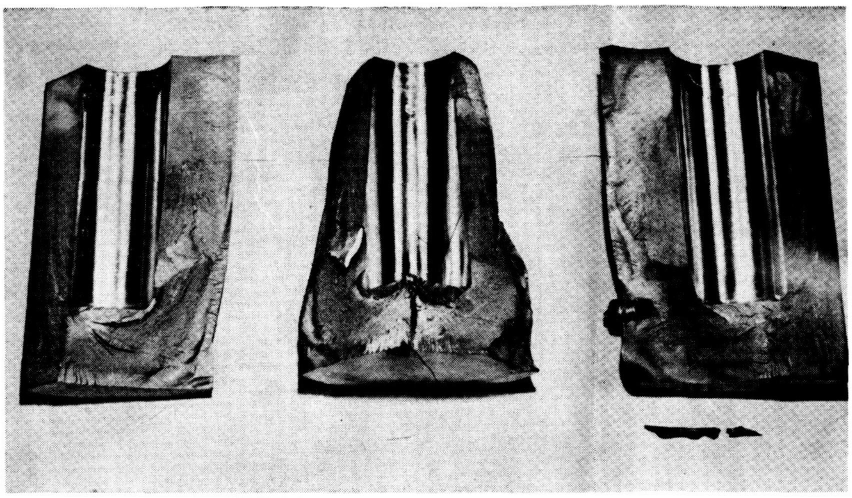


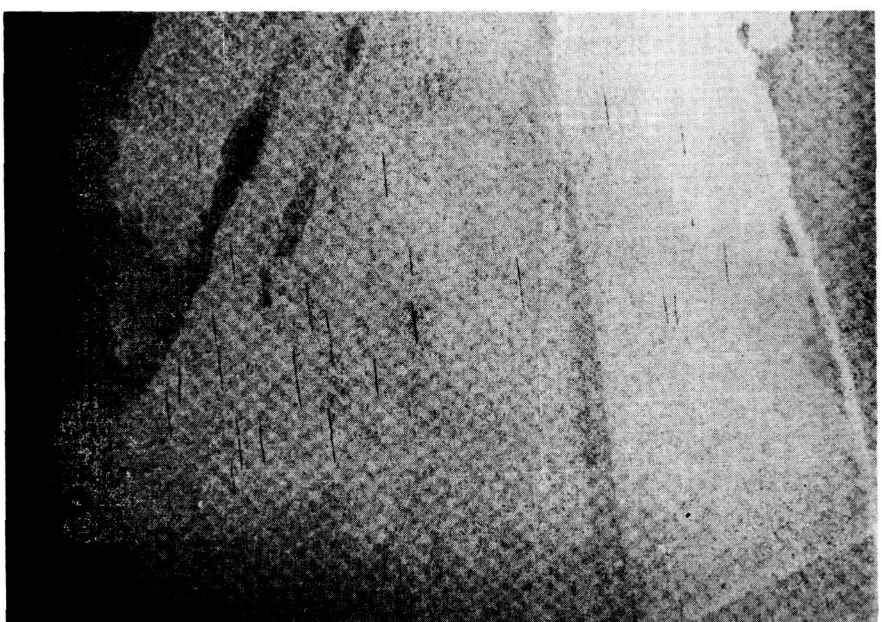
Fig. 3. The three main sections and two *shrapnel-like fragments of the failed die* body as they appeared following failure.

ice period of the original die set, available data indicate that at least 1500 pressing cycles were completed at pressures from 10,000 to 50,000 psi.

The evident success encountered with the original configuration represented a rather convincing precedent for the design of a longer die set. Stress analysis showed that the original configuration would be satisfactory for use at the pressures to be produced within the new and longer die set. Detailed NASA specifications and drawings were completed, and the dies were built by a commercial die manufacturing shop.

Although these replacement dies were designed for use at higher pressures, they were proof tested at 60,000 psi and were placed into service with a maximum allowable operating pressure of 55,000 psi. Every effort was made to keep operating conditions constant for all runs. Pressure was developed slowly, the same pressing fluid was used consistently, and the ambient temperature in the pressing facility was maintained the year round at 60° to 80° F. A log, which included the details of each pressure cycle completed, was maintained to record the use-history of the replacement dies.

Fig. 4. A full size view of the macroetch of the body bore. Dark, vertical lines *in center of photo are grinding checks.*



After the completion of approximately 140 operating cycles, a run was inadvertently made at 60,000 psi. At this pressure, the die body unexpectedly failed and fractured into five pieces. Fortunately, no personnel injuries occurred, and the five fractured metal pieces were all contained within the press housing and associated safety enclosure. Property damage was also confined to this immediate area. Figure 2 is a photo of the pressing facility as it appeared following the failure. Figure 3 shows the three main sections of the die body and the two shrapnel-like fragments.

A mild steel jacket had been placed around the vessel to retard the motion of any fragments that might be created during a possible die body failure. When the vessel ruptured, this jacket was opened along its bolted vertical seams. The bolts constraining the two halves of the jacket failed in tension and were projected against the cast steel walls of the press enclosure. The twisted condition of this jacket indicates that it effectively absorbed much of the blast energy.

Investigation

A preliminary investigation was made into the failure and resulted in the following findings:

1. *Although the dies had been operated at the level of the maximum proof test, the die body design was such as to safely allow operation at higher internal pressures.*

2. *Adequate operational safety procedures had been established in connection with the hydrostatic pressing system.*

3. *The safety procedures had been strictly adherred to by the press operator.*

4. *During most of the 140 pressing cycles completed prior to the failure, pressures between 45,000 and 55,000 psi were produced.*

5. *A readily available turbine oil had been used exclusively as the pressing media. Tests indicated that this particular oil remains fluid at 60,000 psi but quickly begins to solidify above this value. A definite hazard could have existed if solidification had*

occurred within the operating pressure range of the intensifier.

6. *Visual examination of the failed sections indicated no obvious material flaws.*

The die body that failed was also made from Carpenter "R.D.S." oil-hardening tool steel. One of the three large fragments was sent to the Carpenter Steel Company Laboratory at Reading, Pennsylvania, for detailed metallurgical study. The findings of this study were outlined in a report by Mr. Roger L. Mogel of the Technical Services Staff (Ref. 2), and are quoted in the following paragraphs:

"Samples cut from either end of the die body were found to possess no difference in microstructure. A well-developed martensitic phase and a good carbide solution were evident. The material was found to be free of carburization or decarburization but local areas of retempering, 0.005 inch to 0.008 inch deep existed on portions of the inside bore surfaces. Wedge-shaped samples were removed from the outside diameter of the die body, on both ends. Inside hardness measurements indicated that both samples possessed a thorough and constant hardness of Rockwell C58/60 on all surfaces tested. After the chrome had been stripped from the inside diameter of the vessel a macroetch inspection uncovered the presence of small cracks which were identified as grinding checks. The cracks were found to exist in greatest numbers, around a diameter which was about 4 inches below the top surface of the die. This diameter coincided with the position of the apparent failure origins. Checks were also found on the top surface of the die, directly adjacent to the bore." [Fig. 4 shows these small cracks as they appear in the bore. The cracks appear as the small dark lines in the photo.] " *The material was found to be free of foreign inclusions or any metallurgical defect which might otherwise impair its usefulness."*

"The readily noted difference in macro appearance between the top and bottom of the section can be attributed to the way in which the failure propogated. The fine grain structure seen in the upper portion of the die body fragment indicates the early progress of the failure. The failure origins lie at the apex of the smooth flowing, radiating lines. The coarse structure near the bottom of the fragment represents an area where the material was torn apart as the failure progressed downward. Based on these observations, it is concluded that the initiation of the failure can probably be attributed to grinding checks."

What caused checks?

Since these checks are the most likely cause for the initiation of failure, it may be of value to discuss them. The intensifier die body and piston were surface-ground in order to produce a fine finish and an accurate diametral clearance of 0.001 to 0.003 inch. Since the parts were extremely hard, no other surface finishing process was applicable. During such a grinding operation, care must be taken to prevent overheating the work surface. Overheating can result from a shortage of coolant at the work surface or from attempts at removing excessive amounts of stock in a single pass. Evidence of overheating was demonstrated by the local areas of tempering previously mentioned. Rapid overheating and cooling of small areas on a hardened surface can also result in the development of microscopic cracks that occur parallel to the rotational axis of the grinding wheel. Although the cracks are microscopic at the time of their creation, they act as definite stress risers. As the pressure in the die body was cycled, the cracks grew in size as the result of a fatigue process. As the cracks grew, it is reasonable to assume that their effect as stress risers increased. Thus, localized areas probably existed where the actual stress level was much higher than would normally occur for a given internal pressure. Eventually a crack (or cracks) grew to a critical size and the yield strength of the material was exceeded. The hardened material allowed little plastic flow, and failure immediately proceeded.

Other factors

As indicated previously, the die body bore of both intensifiers used at the Lewis Research Center were chrome plated to retard wear and galling. In both cases, no special precautions were taken to eliminate acid remnants of the plating process. It is quite possible that the replacement die body may have become hydrogen embrittled. If such a condition did exist, it may not have been directly responsible for initiation of the failure, but, it could have aided in the almost instantaneous propogation, since an embrittled zone would have offered little resistance to crack propogation.

Thus, if extremely high strength is necessary for an application such as this intensifier die body and a material requiring a high hardness is selected, *extreme care must be taken to prevent the production of stress risers such as grinding checks that can readily lead to premature and unexpected failure.* In order to avoid such difficulties, high-pressure design specialists limit the maximum hardness of such vessels to about Rockwell-C40.

Effective seal

The original die set was placed back in service after a successful proof test and has accumulated well over 100 additional pressing cycles without failure. The intensifier is also used as a pressure source for an auxiliary pressure vessel. A pressure tap (using a standard pipe thread for sealing), has been used to accomplish this task. When the vessel that failed was originally placed into service, difficulty was encountered in maintaining a leak-tight seal. In order to remedy this difficulty, the tap connection threads were coated with a low-temperature soft solder and were wrapped with Teflon tape before installation in the die body. Failure progressed along the centerline of this connection yet the plug remained in place (Fig. 3). This method seems to be an effective means of making a high-pressure seal.

In conclusion, the failure can

probably be attributed to the effect of grinding checks in an excessively hard material. The possibility of hydrogen embrittlement as a contributing factor in the failure, however, cannot be discounted since an embrittled die body would have offered little resistance to crack propogation.

The author would like to extend his thanks to Mr. Roger L. Mogel of the Carpenter Steel Company for his cooperation in the preparation of this article. Photo credit is hereby given to the Carpenter Steel Company for Figure 4.

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Reprinted from November, 1963 issues of SAFETY ENGINEERING and SAFETY MAINTENANCE magazines

Alfred M. Best Company, Inc., New York, N. Y.